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BOONTON ELECTRONICS CORPORATION

General Electric Company

Instruction Manual

Model 72A

Capacitance Meter

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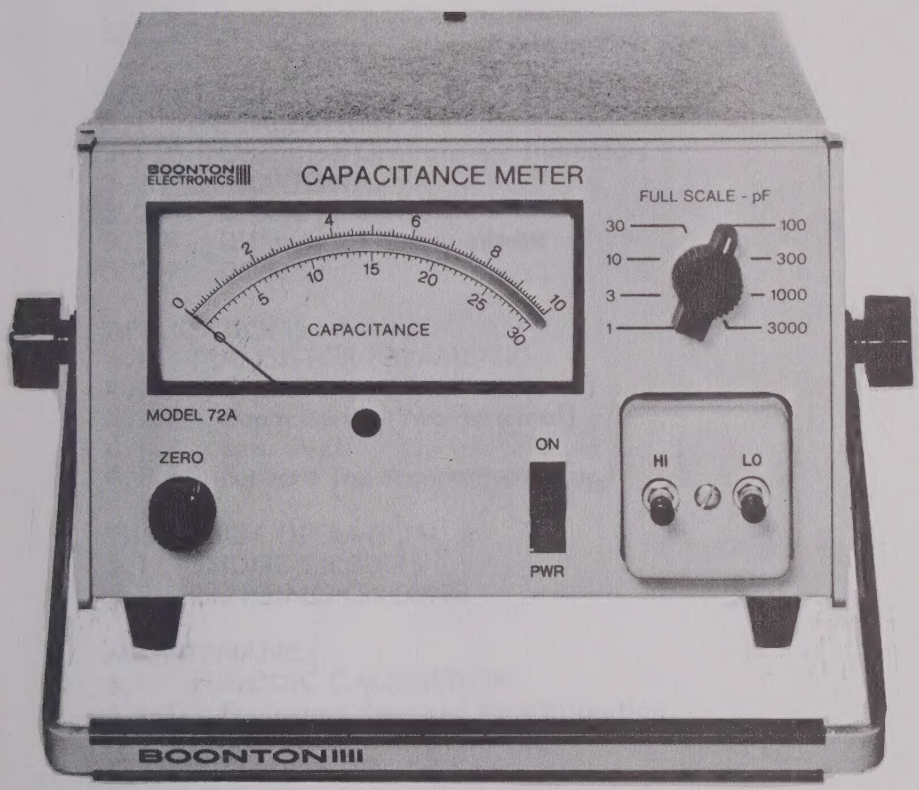


Model 72A Capacitance Meter

TABLE OF CONTENTS

CHAPTER		PAGE
I	INTRODUCTION	1
	1.1 GENERAL	1
II	SPECIFICATIONS	3
III	OPERATION	5
	3.1 INSTALLATION	5
	3.1.1 Operating Controls and Indicators	5
	3.2 OPERATION	7
	3.2.7 Remote Measurement	8
	3.2.8 Differential Measurements	12
	3.2.9 DC Bias	12
IV	APPLICATIONS	13
	4.1 TRANSISTOR PARAMETERS	13
	4.1.1 Capacitance (Three-terminal)	13
	4.1.2 Capacitance (Two-terminal)	14
	4.1.3 Beta (h_{fe})	14
	4.1.4 Forward Transconductance (g_{fs})	15
V	THEORY OF OPERATION	21
	5.1 BRIDGE CIRCUITS	21
	5.2 RANGING CIRCUITS	22
VI	MAINTENANCE	23
	6.1 PERIODIC CALIBRATION	23
	6.1.1 Equipment Required for Calibration	23
	6.2 CALIBRATION PROCEDURE	24
	6.2.1 Oscillator Tuning	24
	6.2.2 Test Level	24
	6.2.3 Low Q Adjustment	24
	6.2.4 Front-Panel Zero	24
	6.2.5 1000 pF Range Zero	25
	6.2.6 Amplifier Gain Adjustment	25
	6.2.7 100 pF Range	25
	6.2.8 300 pF Range	25
	6.2.9 1000 pF Range	25
	6.2.10 10 pF Range	26
	6.2.11 1 pF Range	26

TABLE OF CONTENTS (Cont'd.)

	PAGE
72A - EXTERNAL CONNECTIONS	27
TABLE OF REPLACEABLE PARTS	PL-1

LIST OF ILLUSTRATIONS

FIGURE NO.		PAGE
1	Capacitance Correction, Remote Measurements	9
2	Transistor Capacitance Measurement Connections	18
3	Transistor Beta Measurements	20
4	Transistor Transconductance Measurements	20
5	Simplified Schematic	22
6	Calibration Adjustments	26
7	Rear Terminal Connections	28

CHAPTER I

INTRODUCTION

1.1 GENERAL

The Model 72A Capacitance Meter provides instant, direct reading, three-terminal and differential capacitance measurements from 0.1 to 3000 pF. This coverage is divided into 8 ranges, selected either by panel switch or remotely, arranged in a 1 - 3 - 10 sequence. The solid-state design and crystal-controlled signal source contribute to the high stability and excellent reliability of the instrument.

The 1 MHz test signal is held to a level of 15 mV rms, allowing the measurement of capacitance of semi-conductor devices. The provision for application of dc bias to either or both sides of the specimen makes it possible to measure these devices under operating conditions. The bias voltages may be applied either to the rear-panel terminals provided or to the appropriate pins on the edge connector.

The Model 72A employs an unusual range-switching system using switching diodes and miniature reed relays; the elimination of the switch contacts from the measurement circuits assures a maximum of reliability and stability. The phase-sensitive detection system permits the measurement of even low-Q devices (down to Q = 1) without sensibly degrading the accuracy of the measurement.

Two plug-in connection adapters are supplied with the Model 72A. One adapter, fitted with two sets of coaxial connectors, is intended for use with coaxial cables and remotely located test fixtures for both three-terminal and differential measurements. The second adapter, with two terminal posts, is for wire-lead type components; differential measurements are not possible with this adapter.

A linear dc output is available at rear-panel terminals as well as at the appropriate pins on the edge connector. This feature extends the range of applications beyond ordinary laboratory measurements to include production testing as well as a variety of control functions. Flexibility is further enhanced by the provision of remote ranging terminals; the instrument is fully capable of integration into a controlled test system for rapid, production-line testing.

Remote ranging is controlled by grounding the EXT PROG terminal on the rear edge-connector, disabling the front-panel range switch. Grounding any one of the eight range-line terminals will then select that range.

Connection to the rear panel edge-connector should be made with an Amphenol Type 225-22221-101 plug.

CHAPTER II

SPECIFICATIONS

Capacitance Range:	0.1 to 3000 pF
Full Scale Ranges:	1, 3, 10, 30, 100, 300, 1000, 3000 pF
Accuracy:	0.5% rdg ± 0.5% fs (Q > 5)* 1.0% rdg ± 0.5% fs (Q = 1 to 5)* *Add 0.005 pF on lowest range
Resolution:	0.5% of fs on all ranges
Meter:	4-1/2" taut-band type; two linear scales, 0 to 10 (0.1 per division), and 0 to 30 (0.5 per division).
DC Output:	1 volt fs ± 0.5% at 1, 10, 100, 1000 pF; 3 volts fs ± 0.5% at 3, 30, 300, 3000 pF
Linearity:	0.1% rdg ± 0.01% fs.
Response Time:	< 1 ms.
Source Resistance	1 kΩ
External Bias:	HI to GND: ± 200 V max. LO to GND: ± 400 V max. LO to HI: ± 600 V max. (floating supply)

Test Signal:

1 MHz, crystal-controlled; 15 mV rms,
DIFF/TEST terminal balance 0.02%.

Temperature Influence:

Temperature Range	Max. Influence
Reference 21°C to 25°C	0
Normal 18°C to 30°C	0.2% of rdg
Extreme 10°C to 40°C	0.5% of rdg

Accessories Furnished:

Two connection adapters:

a) BNC for remote connections to TEST and DIFF terminals.

b) Grip-posts for local connection of axial-lead components.

Accessories Available:

Single rack-mounting kit (mounts left or right) 92-1A.
Dual rack-mounting kit 92-1B.

Power Requirements:

115/230 V ± 10%; 50 to 400 Hz; 16 watts

Dimensions:

5.2" high, 8.3" wide, 12" deep (132 x 211 x 305 mm)

Weight:

Net 7.2 lbs. (3.29 kg)

CHAPTER III

OPERATION

3.1 INSTALLATION

Each instrument has been inspected and tested at the factory for full compliance with all specifications before packing. Should any indication of shipping damage be apparent upon unpacking, be sure to notify the carrier and the factory immediately. It is recommended that the special packing materials be saved for use in the event that the instrument must be re-shipped in the future.

3.1.1 Operating Controls and Indicators

ITEM	FUNCTION
FULL SCALE pF	This switch selects the full-scale range of the instrument; it has 8 positions ranging from 1 pF to 3000 pF full-scale.
PWR Switch	This rocker-type switch turns on the ac primary power. The translucent plastic rocker also serves as the pilot light.
ZERO Control	This control operates a differential capacitor to balance out capacitance across the TEST terminals contributed by exposed terminations of connecting cables, test fixtures, etc. This is a dual ratio control, with low torque over 270° of rotation, shifting to a higher torque vernier ratio beyond this point.

METER

A 4-1/2 inch taut-band meter with two linear scales, reading 0 to 10 with 0.1 per division, and 0 to 30 with 0.5 per division.

(The following items are on the rear panel)

RECORDER Terminals

A dc voltage proportional to the meter reading is available at these terminals.

F.S. output: 1 volt (1-series ranges)
3 volt (3-series ranges)
Source impedance: 1000 Ω

BIAS Terminals

External dc bias may be applied to the HI and LO Test terminals via these posts. The maximum values are ±200 volts from HI terminal to ground, and ±400 volts from the LO terminal to ground. The sum of these two voltages (600 Vdc) may be applied between the HI and the LO posts, but the bias supply should be floating (no connection to ground) for this application.

Slide Switch

This switch must be set to the appropriate line voltage - 115 or 230 volts, 50/400 Hz.

Fuse Holder

This contains the main line fuse, which should be either a 0.06 ampere for 230 V or a 0.10 ampere for 115 V.

P102

22-pin edge connector for remote ranging and readout connections.

Test Adapter

These banana plugs are used for storing the unused connection adapter.

This safety requirement symbol has been adopted by the International Electrotechnical Commission, Document 66 (Central Office) 3, paragraph 5.3 which directs that an instrument be so labeled, if, for the correct use of the instrument, it is necessary to refer to the instruction manual. In this case it is recommended that reference be made to the instruction manual when connecting the instrument to the proper power source.

3.2 OPERATION

3.2.1 See that the rear-panel voltage selector switch is in the proper position for the line voltage used, adjust (if necessary) the mechanical zero screw of the meter, plug the instrument into a power outlet, and allow it to warm up for a few minutes.

3.2.2 Plug the appropriate test connection adapter into the front-panel receptacle. If remote or other coaxially-connected components are to be measured, connect all cables and test fixtures to the TEST jacks of the connection adapter.

3.2.3 Switch the instrument to the lowest range (1 pF fs). Set the meter reading to zero, using the ZERO control.

NOTE: The ZERO control uses a dual-ratio vernier to drive a variable air capacitor having a full 360° of rotation. The ZERO control turns easily for about 270°, at which point the ratio shifts from 36:1 to 6:1 and torque increases abruptly.

3.2.4 When more than a few inches of coaxial cable is used to connect the instrument to a remote test fixture, some attention must be given to the shunt capacitance of the cable. To maintain the specified accuracy, the values shown in the following table should not be exceeded.

Maximum Cable Shunt Capacitance

A. HI post to ground:

RANGE	MAX. C
1 pF	100 pF
3	100
10	250
30	250
100	500
300	500
1000	500
3000	500

B. LO post to ground:

500 pF max. on all ranges.

3.2.5 The instrument is now ready for use. Once the zero setting has been made on the lowest range, it will hold on all other ranges.

3.2.6 The ZERO adjustment has sufficient range to compensate for approximately 5 pF of shunt capacitance across the TEST terminals. If this range is insufficient, a small capacitor (value determined experimentally) can be connected across the DIFF terminals to effect zero setting within the range of the ZERO control.

3.2.7 Remote Measurement

The remote measurement of capacitance via coaxial cables introduces a measurement error owing to the transmission line effect on the test voltage

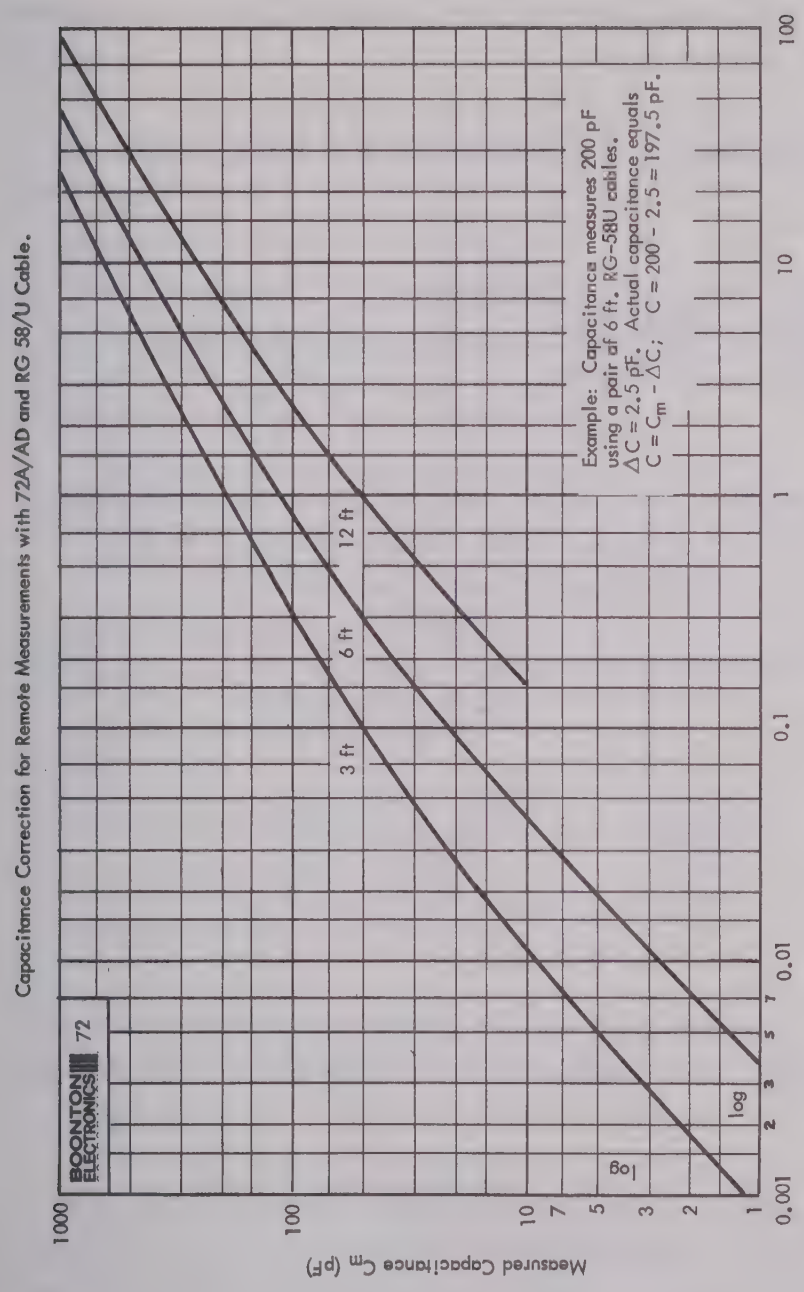


Figure 1. Capacitance Correction

transmitted from the LO terminal, and on the received current at the HI terminal.

The combined effect is such that the ratio of measured capacitance to actual capacitance is,

$$C_m/C = \frac{1 + j\omega Cr}{[\cos \beta\ell - \omega C Z_o (\sin \beta\ell)]^2 \left[1 + j \frac{\omega Cr (\cos \beta\ell) + (\sin \beta\ell) r / Z_o}{\cos \beta\ell - \omega C Z_o (\sin \beta\ell)}\right]}$$

where $\beta\ell$ = the electrical length of each line, in degrees

Z_o = the characteristic impedance of the line, in ohms
(Note: At 1 MHz, Z_o for RG-58/U is approximately 57.5 ohms)

and r = the equivalent resistance of the Capacitance Meter from HI terminal to ground.

Range	r
1 pF and 3 pF	140 ohms
10 pF and 30 pF	7 ohms
100 pF and above	1 ohm

For the 72A Capacitance Meter, the error is positive and its magnitude is shown in Figure 1 as a function of the measured capacitance, C_m, and cable length, ℓ.

The error is not shown for the lower two ranges for 12 foot lengths of cable, as the capacitive loading of the HI test terminal is excessive for lengths of RG-58/U greater than about 3.5 feet, and lengths of about 8 feet for the 10 pF and 30 pF ranges.

When calculating $\beta\ell$, which is the electrical length in degrees of each of the two cables, it is necessary to know the velocity of propagation of the cable at 1 MHz. Samples of RG-58/U which were tested indicate a relative velocity of 63.5%. The impedance of the same cable measured 57.5 ohms at 1 MHz.

It is imperative that the shields of both ends of the coaxial cable be tied together with a low resistance, low inductance strap for the correction curves and equation to be valid.

3.2.7.1 For short lengths of cable, a reasonable correction may be made based upon the effect of the series inductance of both lengths of cable. The measured capacitance, C_m, of a specimen will differ from the true capacitance, C_t; the error will be seen as an apparent increase in capacitance in accordance with the following expression:

$$C_m = \frac{C_t}{1 - \omega^2 L C_t} = \frac{C_t}{1 - (X_L / X_{C_t})}$$

Or, if the true capacitance is required:

$$C_t = \frac{C_m}{1 + \omega^2 L C_m} = \frac{C_m}{1 + (X_L / X_{C_m})}$$

Where L = the combined series inductance of BOTH lengths of connecting cables and the inductance of the sample (generally small with respect to the cable's inductance).

As an approximation, the inductance/foot of RG-58/U cable (with shields common at both ends) is about 0.091 μH.

3.2.8 Differential Measurements

Measurement of the capacitance differential between two specimen capacitors can be made by connecting the smaller sample to the DIFF terminals, and the larger to the TEST terminals. The display will indicate the capacitance difference between the two; by switching down to the next lower range the resolution will be improved. The capacitor connected to the DIFF terminals may be as large as the full-scale value of the selected range without introducing serious error.

Excess fixture capacitance across the TEST terminals beyond the normal range of the ZERO control may be balanced out by the addition of a capacitor to the DIFF terminals. (See Par. 3.2.6) Up to twice the full-scale value for the range in use may be used in this application without introducing additional error.

3.2.9 DC Bias

DC Bias voltage may be applied to either or both sides of the specimen via the rear-panel bias terminals, or the proper pins on the rear edge connector. The applied voltages should not exceed ± 200 volts from the HI terminal to ground, or ± 400 volts from the LO terminal to ground. When bias is applied to one side only, the other bias terminal must be connected to ground.

The sum of the two voltages (600 volts dc) may be applied between the HI and the LO terminals. In this connection, however, the 200-volt maximum limit of the HI side to ground may be exceeded; it is therefore strongly recommended that the bias supplied not be grounded. (An internal voltage divider establishes the ground point.)* The bias lines are internally protected by 30 mA fuses.

*Internal voltage divider resistance values are 240 kΩ from HI to ground and 510 kΩ from LO to ground.

CHAPTER IV

APPLICATIONS

4.1 TRANSISTOR PARAMETERS

The Model 72A is capable of measuring the small-signal capacitance and forward gain parameters of both bipolar and unipolar transistors at 1 MHz. Capacitance and transconductance are measured with a test signal level of 15 millivolts; beta is measured with a base signal current of approximately 100 nanoamperes.

The principle of operation of the 72A is fundamentally that of a transmission test set; the test capacitance is interposed between a low-level signal generator of fixed known amplitude and phase, and a calibrated phase-sensitive detector. It is evident that the forward gain parameters of transistors may also be measured, provided that the phase of the output current is proper, or suitably altered. The necessary external circuitry and components are described in the following text. Parameters that can be measured include the following:

4.1.1 Capacitance (Three-terminal)

NOTE: When measuring the capacitance of transistors, it is imperative to remember that a signal applied to the input of the test device will appear amplified in some form at the output (usually with a phase reversal). Capacitance measurements must be made with the output of the device connected to the low test-terminal (generator) and the input of the device connected to the high test-terminal (detector).

C_{iss} Input capacitance between gate and source with guarded drain. Device under test is fully biased. $V_{GS} = 0$.

C_{rss} Reverse transfer capacitance between drain and gate. Source guarded. Device under test is fully biased. $V_{GS} = 0$.

C_{eb} Emitter-to-base capacitance. Connector guarded. Emitter reverse biased. $V_{CE} = 0$ (o.c. for dc).

C_{ce} Collector-to-emitter capacitance. Base guarded. Collector reverse biased. $V_{BE} = 0$ (o.c. for dc).

C_{re} Collector-to-base capacitance. Emitter guarded. Device under test is fully biased.

C_{cb} Collector-to-base capacitance. Emitter guarded. Collector reverse biased. $I_E = 0$ (o.c. for dc).

4.1.2 Capacitance (Two-terminal)

C_{ob} Collector-to-base capacitance. Emitter is open-circuited for both ac and dc. Collector is reverse biased.

NOTE: External connections for the above measurements are shown in Figure 2.

4.1.3 Beta (h_{fe})

A sensibly constant base current, i_b, of 94 nanoamperes can be generated with the aid of a 1.0 pF capacitor connected between the low differential (LO DIFF) terminal of the 72A Capacitance Meter and the base of the

of the transistor under test. The collector current, which equals βi_b, is fed to the high test terminal (HI TEST) and the instrument responds as though a capacitance of β times 1 pF were connected to its terminals. The value of indicated capacitance in picofarads is equal to beta (h_{fe}). The measurement of beta should be made under full bias conditions. In this arrangement, the base current is independent (very nearly) of the input resistance of the transistor, owing to the quadrature relation between the reactance of the current source and the input resistance.

The low differential terminal is used for the current source to offset the 180-degree phase reversal of current in the transistor.

The variable series capacitor in the base circuit (see Figure 3) must be adjusted for a value of 1.0 pF. This is simply accomplished by connecting a small jumper (unity-gain transistor) between the base and collector socket terminals, which permits the direct measurement of this capacitance. If the LO DIFF terminal is used, the reading should be adjusted for - 1.0 pF, using the dc recorder output, or the LO TEST terminal may be temporarily used for a reading of +1.0 pF on the meter.

Should the transistor socket and its associated circuitry have excessive capacitance from the base terminal to ground, it can be absorbed with a simple parallel-resonant circuit, using a high L/C ratio for maximum impedance. (Figure 3)

4.1.4 Forward Transconductance (g_{fs})

The 72 Series Capacitance Meters are calibrated for an input current of $+je_g\omega C/\underline{\theta}$, where C is the full-scale value of capacitance for any given range. Connecting the gate of a unipolar transistor to the LO TEST terminal will, by definition, generate a drain current of $e_g g_{fs}$, provided that the external drain-circuit impedance is small. Unfortunately, the phase of the drain current lacks the required +90 degrees.

A network is needed which presents a low impedance to the drain, and which provides the necessary phase shift of +90 degrees. The circuit shown in Figure 4, Page 20, satisfies these conditions. The resistor R is the calibrating resistor for the full-scale value of g_{fs}. Its value is readily derived. The instrument is calibrated for a high-terminal current of,

$$i_c = e_g \omega C \angle 90°$$

The actual drain current is,

$$i_d = e_g g_{fs}$$

The voltage induced in the secondary of the transformer is,

$$e' = j i_d \omega M \angle 90° \quad \text{(polarity arranged for +M)}$$

To achieve a full-scale indication for a given value of g_{fs}, the resistor R must have the value,

$$R = e'/i_c = \frac{e_g g_{fs} \omega M \angle 90°}{e_g \omega C \angle 90°} = g_{fs} M/C$$

where

$R \gg \omega L_s$ for the current to have the correct phase; M is the mutual inductance of the transformer, and equals,

$$M = k\sqrt{L_p L_s}$$

The coefficient of coupling, k, may be easily measured by measuring the primary inductance with the secondary open-circuited, then short-circuited.

$$k = \sqrt{1 - (L_{sc}/L_{oc})}$$

If the resistor R is selected for a full-scale reading of 1000 μmhos on the 100 pF range, the instrument will read:

C Range	g_{fs} Range
100 pF	1000 μmhos
300 pF	3000 μmhos
1000 pF	10,000 μmhos
2000 pF	20,000 μmhos

A typical toroidal transformer might have the following circuit values:

$$L_p = 250\ \mu H$$
$$L_s = 5\ \mu H$$
$$k = 0.935$$

from which,

$$M = 33\ \mu H$$

The series primary capacitance for resonance must equal 100 pF (approximately), and for a full-scale range of 1000 μmhos on the 100 pF range, the calibrating resistor should equal:

$$R = (1000)(33)/100 = 330\ \Omega$$

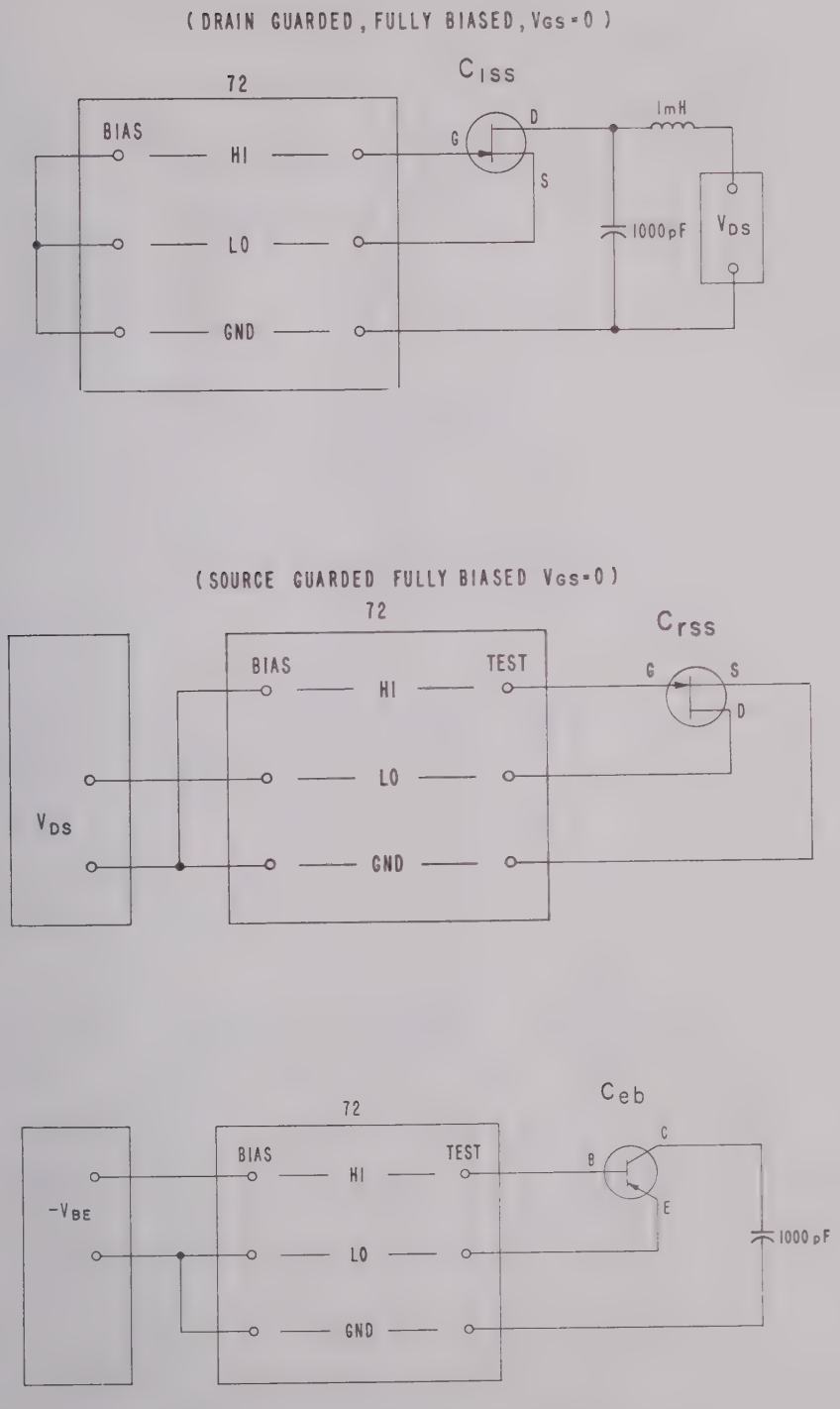
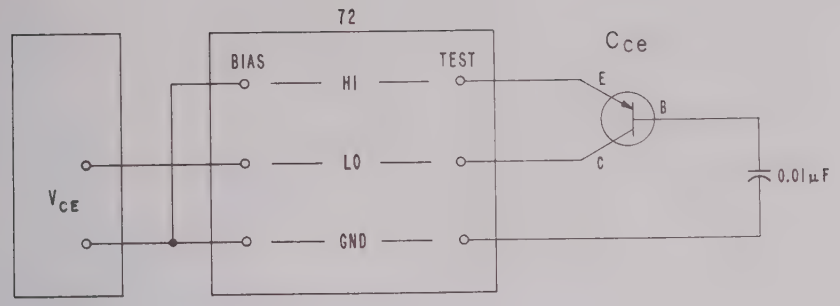
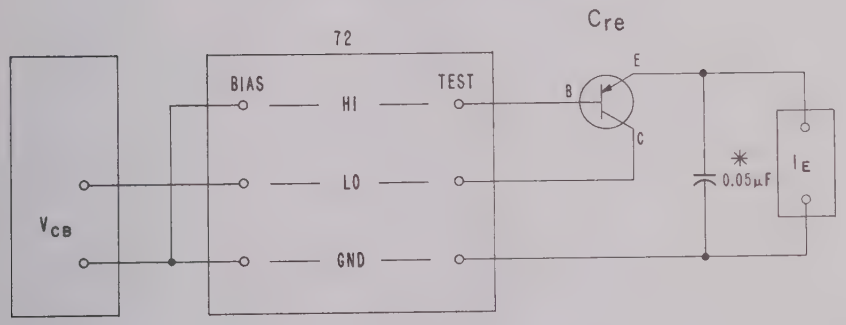
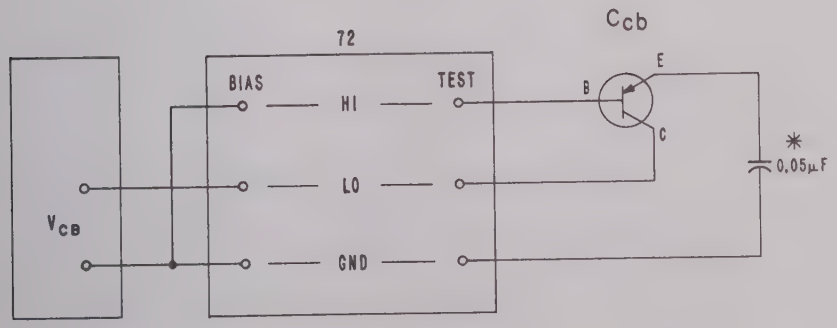


Figure 2. Transistor Capacitance Measurements



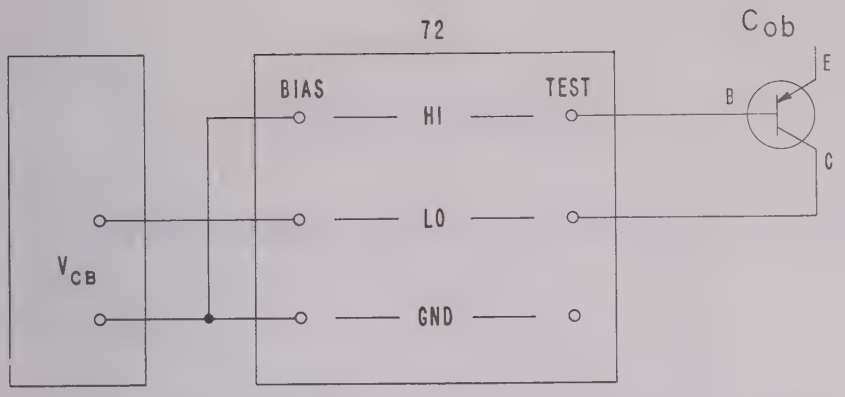
(EMITTER GUARDED, FULLY BIASED)

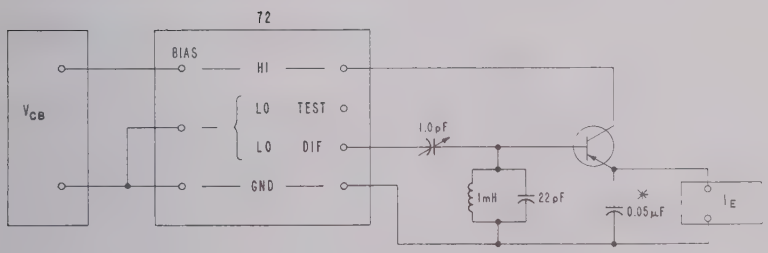




* A better by-pass obtains with a 2.5 μH inductor in series with a 0.01 μF capacitor.

Figure 2. (Cont'd.)





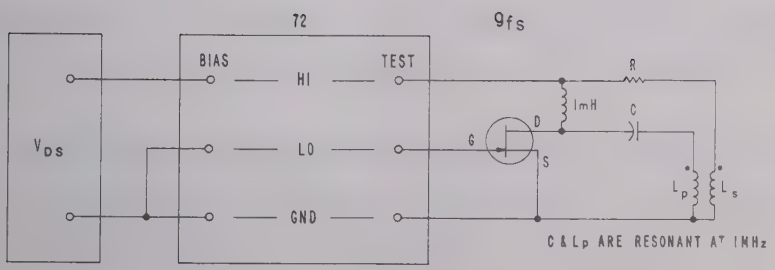


Figure 4. Transistor Transconductance Measurement

CHAPTER V

THEORY OF OPERATION

(Refer to the Simplified Schematic, Figure 5, in connection with this explanation.)

5.1 BRIDGE CIRCUITS

The output of the 1 MHz crystal-controlled oscillator appears across the secondary of the transformer whose center-tap is at RF ground. One end of this winding goes to the LO TEST terminal, and the other end to the LO DIFF terminal. The HI terminals are connected together and lead to the output connection of the measuring section. A differential capacitor (ZERO) has its stators connected across the transformer secondary winding, and its rotor to the common HI post connection.

With the instrument operating, and with both TEST and DIFF terminals open, the only signal appearing at the output of this section would be the result of the residual capacitances of the terminals and any fixtures connected to them. Adjustment of the differential capacitor (ZERO control) balances out this signal, within the limits specified in Section 3.2.4, resulting in zero output from the measuring section.

When a specimen capacitor is connected between the LO and HI terminals, a current directly proportional to its susceptance flows through the low-impedance series-resonant LC circuit to ground. (The series-resonant circuits for each range are selected by the range switching circuits.) The resultant voltage appearing across the capacitive part of the series circuit is applied, through a tuned amplifier, to the synchronous detector.

The synchronous detector, gated by the crystal oscillator, converts the 1 MHz signal to dc and applies it to the dc amplifier section. The output of the dc amplifier drives the panel meter and is available at the DC OUT terminals, supplying a dc analog output voltage for external indication or control purposes.

5.2 RANGING CIRCUITS

Range switching in the 72A is accomplished by a combination of the panel range switch, switching diodes, and miniature reed relays. The panel switch handles only control voltages; no signal currents pass through its contacts, which eliminates a frequent source of errors and improves reliability.

The switching diodes are biased off by the 2.4 volt differential between the +6.6 volts on their cathodes and the +4.2 volts on their anodes. When range switch contacts are closed, the cathode of the appropriate diode is grounded for dc through an rf choke and 10 kΩ resistor. As it then has a net positive bias on its anode, the diode is switched to the conducting state and thereby connects one end of its associated range network to the input of the 1 MHz amplifier. At the same time, the range switch energizes the associated reed relay which connects the other end of the range network to the output of the measuring section.

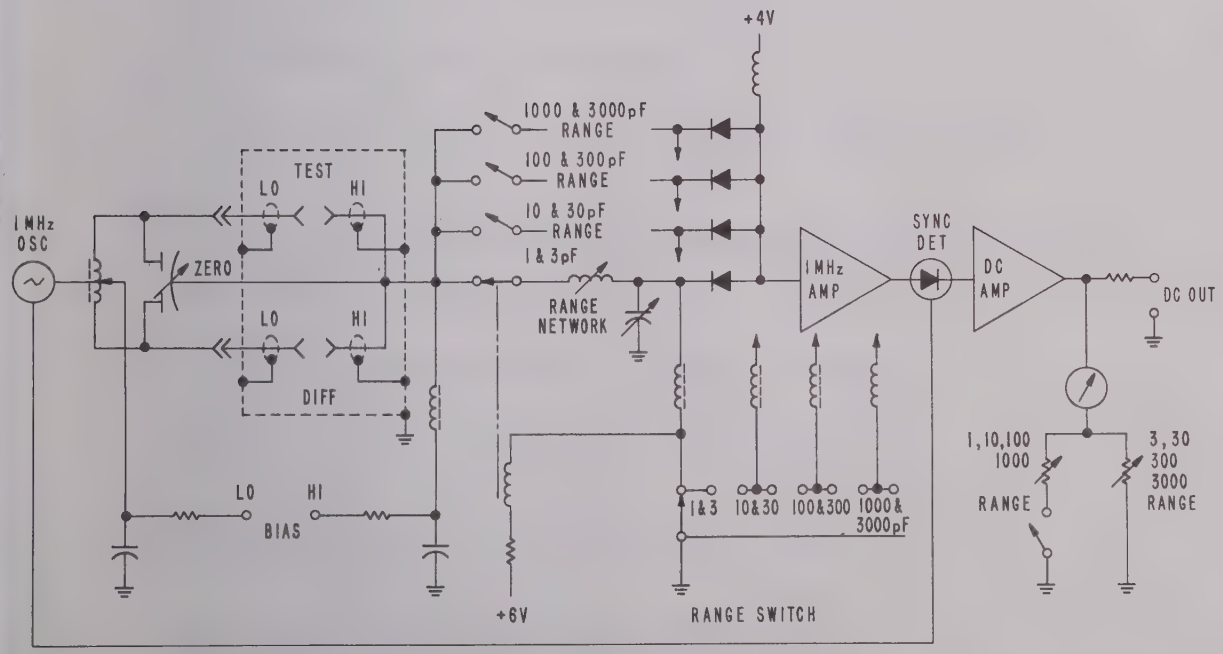


Figure 5. Simplified Schematic

CHAPTER VI

MAINTENANCE

6.1 PERIODIC CALIBRATION

The Model 72A is designed to provide trouble-free operation over long periods of time. However, as with any measuring instrument, it is advisable to follow a program of periodic calibration against known standards. Should there be any indication of operational malfunction, of course, such a calibration check will also be an aid in pinpointing the trouble before detailed troubleshooting is attempted.

6.1.1 Equipment Required for Calibration

a. Digital or differential dc voltmeter, ± 0.005% accuracy.

b. DC voltmeter, such as a standard VOM.

c. RF Millivoltmeter, such as a Boonton Electronics Model 92A or 92AD.

d. 100 pF ± 0.25% standard capacitor, switchable from high Q to a Q of 3. (BEC Model 71-1A or equivalent)

e. 1000 pF ± 0.1% standard capacitor. (BEC CS-1000)

f. 300 pF ± 0.1% standard capacitor. (BEC CS-300)

g. 100 pF ± 0.1% standard capacitor. (BEC CS-100)

h. 10 pF ± 0.1% standard capacitor. (BEC CS-10)

i. 1 pF ± 0.1% standard capacitor. (BEC CS-1)

6.2 CALIBRATION PROCEDURE

Remove the screw on the top rear of the instrument cover and take off the cover. Turn the instrument on, allow it to warm up for a half-hour, then follow the steps outlined in the following pages.

NOTE: Refer to Figure 6 for identification of the controls mentioned in the following procedure.

6.2.1 Oscillator Tuning

Switch the instrument to the 1000 pF range, and connect the dc voltmeter to test point TP 1. Adjust C204 for a maximum reading on the voltmeter, which will normally be in the range of +5 to +14 volts.

6.2.2 Test Level

With the instrument still on the 1000 pF range, connect the RF Millivoltmeter between the LO terminal on the front panel and ground. Adjust R209 for a reading of 15 mV ± 2 mV.

6.2.3 Low Q Adjustment

Switch the 72A to the 100 pF range. Connect the 100 pF ±0.25% standard capacitor (Model 71-1A) to the TEST terminals and record the capacitance reading. Switch the standard to the low Q position (Q = 3) and again read the capacitance value. If the two values obtained are not the same, adjust C229 until they coincide.

6.2.4 Front-Panel Zero

Switch instrument to the 1 pF range. Connect dc voltmeter to the REC terminals on the rear panel. With nothing connected to the TEST terminals, adjust the front panel ZERO control for a zero indication on the voltmeter.

6.2.5 1000 pF Range Zero

With nothing connected to the TEST terminals, and the dc voltmeter connected to the REC terminals, set the instrument to the 1000 pF range. Adjust R246 for a zero reading on the voltmeter.

6.2.6 Amplifier Gain Adjustment

Switch the 72A to the 100 pF range, connect the 100 pF ± 0.1% standard capacitor (CS-100) to the TEST terminals, and the digital dc voltmeter to the REC terminals. Adjust R126 for a voltmeter reading of +1 V ± 0.1%.

6.2.7 100 pF Range

With the 72A on the 100 pF range, connect the 100 pF ± 0.1% standard capacitor (CS-100) to the TEST terminals. Adjust R142 for a reading of 100 pF full-scale.

6.2.8 300 pF Range

Switch the 72A to the 300 pF range and connect the 300 pF ± 0.1% standard capacitor (CS-300) to the TEST terminals. Adjust R147 for a reading of 300 pF full-scale.

6.2.9 1000 pF Range

Switch the 72A to the 1000 pF range and connect the 1000 pF ± 0.1% standard capacitor (CS-1000) to the TEST terminals. Adjust C116 for an indication of 1000 pF full-scale.

6.2.10 10 pF Range

Switch the 72A to the 10 pF range and connect the 10 pF ± 0.1% standard capacitor (CS-10) to the TEST terminals. Adjust C113 for a reading of 10 pF full-scale.

6.2.11 1 pF Range

Switch the 72A to the 1 pF range and connect the 1 pF ± 0.1% standard capacitor (CS-1) to the TEST terminals. Adjust C106 for a reading of 1 pF full-scale.

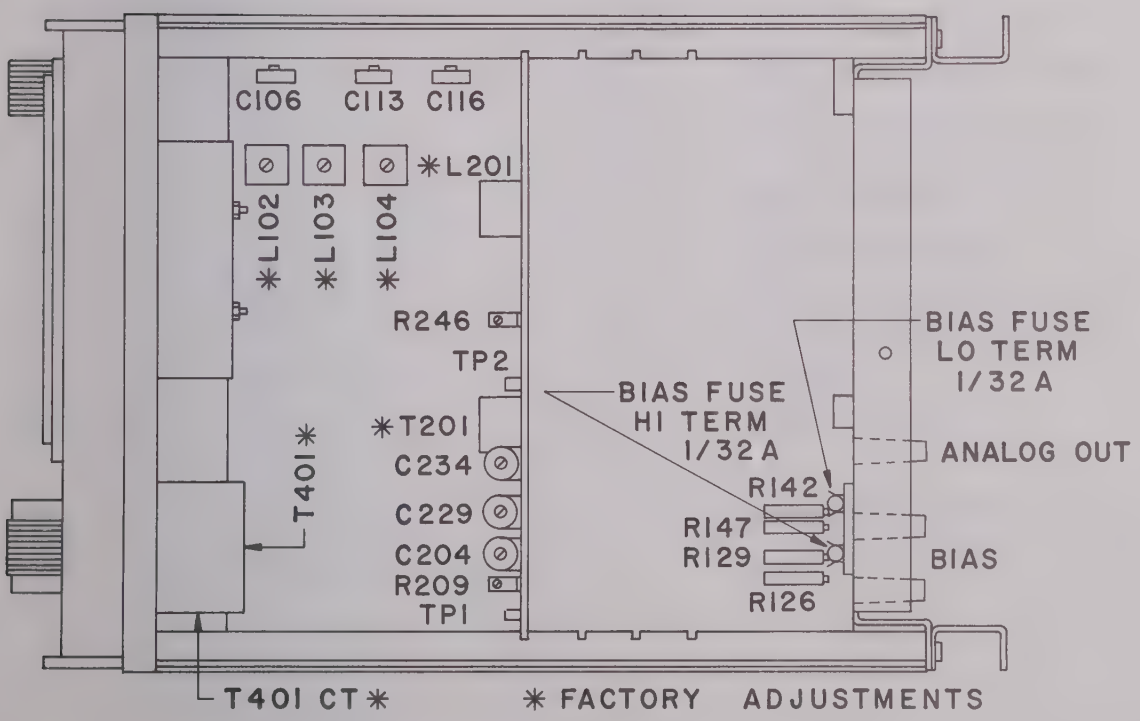


Figure 6. Calibration Adjustments

72A EXTERNAL PROGRAMMING PIN ASSIGNMENTS

TERMINAL	FUNCTION	REMARKS
A	LO TERMINAL BIAS	±400 V dc max.
B	GND	
C	EXTERNAL PROGRAM	Connect to GND to disable front panel programming.
1	HI TERMINAL BIAS	±200 V dc max.
2	RECORDER OUTPUT (DC ANALOG)	+1 V fs 1-10-100-1000 range +3 V fs 3-30-300-3000 range $\not\equiv \cong$ 1 kΩ
3	GND	
5	1 pF RANGE	External range programming inputs. Logic 0 or connection to common selects corresponding range. These lines may be used as outputs to indicate current operating range: the range line corresponding to the operating range will be at logic 0. (logic 0 < +0.5 V)
6	3 " "	
7	10 " "	
8	30 " "	
9	100 " "	
10	300 " "	
11	1000 " "	
12	3000 " "	
20	-15 V DC	Power for BEC supplied options only.
21	+15 V DC	

Figure 7. Rear Terminal Connections

TABLE OF REPLACEABLE PARTS

MODEL 72A

CAPACITORS

Reference		Description	BEC Part No.
C101	Capacitor, fixed	100 nF 630 V	234091
C102	" "	"	"
C103	" "	82 pF ± 5%	200074
C104	" "	910 pF ± 1%	200075
C105	" "	10 nF ± 1%	203017
C106	Capacitor, variable	2 - 20 pF Blue	281005
C107	Capacitor, fixed	68 pF ± 5%	200031
C108	" "	82 pF ± 5%	200074
C109	" "	680 pF ± 1%	200015
C110	" "	1 nF 500 V	224114
C111	" "	"	"
C112	" "	100 nF 250 V	234080
C113	Capacitor, variable	5 - 50 pF Green	281006
C114	Capacitor, fixed	100 nF 250 V	234080
C115	" "	"	"
C116	Capacitor, variable	5 - 50 pF Green	281006
C117	Capacitor, fixed	100 nF 250 V	234080
C118	" "	1 nF 500 V	224114
C119	" "	100 nF 250 V	234080
C120	" "	22 nF 250 V	234079
C121	" "	30 pF ± 5%	200073
C122	" "	250 µF 40 V	283207
C123	" "	"	"
C124	" "	22 nF 250 V	234079
C125	" "	100 µF 25 V	283105
C126	" "	"	"
C201	Capacitor, fixed	100 nF 250 V	234080
C202	" "	1 nF 500 V	224114
C203	" "	"	"
C204	Capacitor, variable	15 - 60 pF	281008
C205	Capacitor, fixed	100 nF 250 V	234080
C206	" "	"	"
C207	" "	"	"
C208	" "	1 nF 500 V	224114
C209	" "	100 nF 250 V	234080
C210	" "	27 pF " 5%	200076
C211	" "	1 nF 500 V	224114

Reference		Description	BEC Part No.
C212	Capacitor, fixed	250 pF ± 5%	200036
C213	" "	100 nF 250 V	234080
C214	" "	30 pF ± 5%	200073
C215	" "	10 nF 100 V	224119
C216	" "	160 pF ± 5%	200048
C217	" "	100 nF 250 V	234080
C218	" "	39 pF ± 5%	200025
C219	" "	100 nF 250 V	234080
C220	" "	1 nF 500 V	224114
C221	" "	37 pF ± 5% 500 V	220119
C222	" "	100 nF 250 V	234080
C223	" "	"	"
C224	" "	"	"
C225	" "	"	"
C226	" "	1 nF 500 V	224114
C227	" "	100 nF 250 V	234080
C228	" "	"	"
C229	Capacitor, variable	5 - 18 pF	281007
C230	Capacitor, fixed	10 nF 100 V	224119
C231	" "	680 pF ± 1%	200015
C232	" "	"	"
C233	" "	39 pF ± 5%	200025
C234	Capacitor, variable	15 - 60 pF	281008
C235	Capacitor, fixed	22 nF 250 V	234079
C236	" "	"	"
C237	" "	"	"
C238	" "	"	"
C301	Capacitor, fixed	50 µF 25 V	283159
C303	" "	15 nF 200 V	234063
C401	Capacitor, fixed	680 pF ± 1%	200015
C402	Capacitor, variable	1.8 - 8.7 pF	275138
C403	Capacitor, fixed	10 nF 600 V	234077
C404	" "	"	"

RESISTORS

R101	Resistor, fixed	5.1 kΩ 5% 1/2W	301104
R102	" "	"	"
R103	" "	1.3 kΩ 5% 1/2W	301090

Reference		Description	BEC Part No.
R104	Resistor, fixed	100 kΩ 5% 1/2W	301135
R105	" "	11 kΩ 5% 1/2W	301112
R106	" "	10 kΩ 5% 1/2W	301111
R107	" "	"	"
R108	" "	"	"
R109	" "	"	"
R110	" "	100 kΩ 5% 1/2W	301135
R111	" "	5.1 kΩ 5% 1/2W	301104
R112	" "	2 kΩ 5% 1/2W	301094
R113	" "	3 kΩ 5% 1/2W	301098
R114	" "	1 kΩ 5% 1/2W	301087
R115	" "	3.9 kΩ 5% 1/4W	300096
R116	" "	"	"
R117	" "	5.1 kΩ 5% 1/4W	300099
R118	" "	"	"
R119	" "	"	"
R120	" "	"	"
R121	" "	3.9 kΩ 5% 1/4W	300096
R122	" "	5.1 kΩ 5% 1/4W	300099
R123	" "	"	"
R124	" "	"	"
R125	" "	"	"
R126	Resistor, variable	1 kΩ 20% 1W	311256
R127	Resistor, fixed	10 kΩ 1% 3/8W	326376
R128	" "	100 Ω 5% 1/2W	301063
R129	Resistor, variable	20 kΩ 10% 1W	311266
R130	Resistor, fixed	4.7 MΩ 5% 1/2W	301175
R131	" "	10 MΩ 5% 1/2W	301183
R132	" "	63.4 kΩ 1% 3/8W	340455
R133	" "	10 kΩ 1% 3/8W	326376
R134	" "	2 kΩ 5% 1/2W	301094
R135	" "	24 kΩ 5% 1/2W	301120
R136	" "	"	"
R137	" "	2 kΩ 5% 1/2W	301094
R138	" "	1.3 kΩ 5% 1/2W	301090
R139	" "	8.2 Ω 5% 1/2W	301505
R141	" "	26.1 kΩ 1% 3/8W	340408
R142	Resistor, variable	5 kΩ 10% 1W	311268
R143	Resistor, fixed	4.7 Ω 5% 1/2W	301508
R144	" "	3.65 kΩ 1% 3/8W	340307
R145	" "	100 Ω 5% 1/4W	300058
R146	" "	54.9 kΩ 1% 3/8W	340447
R147	Resistor, variable	5 kΩ 10% 1W	311268
R149	Resistor, fixed	1.37 kΩ 1% 3/8W	340257
R150	" "	100 Ω 5% 1/4W	300058
R151	" "	3.3 kΩ 5% 1/2W	301099
R152	" "	390 Ω 5% 1/2W	301077

Reference		Description	BEC Part No.
R201	Resistor, fixed	47 kΩ 5% 1/2W	301127
R202	" "	100 kΩ 5% 1/2W	301035
R203	" "	160 kΩ 5% 1/2W	301140
R204	" "	1 kΩ 5% 1/2W	301087
R205	" "	1.5 kΩ 5% 1/2W	301091
R206	" "	270 Ω 5% 1/2W	301073
R207	" "	10 Ω 1% 1/4W	315039
R208	" "	1/21 kΩ 1% 1/4W	315089
R209	Resistor, variable	1 kΩ 10% 0.75W	311226
R210	Resistor, fixed	8.25 kΩ 1% 3/8W	326309
R211	" "	2 kΩ 5% 1/2W	301094
R212	" "	562 Ω 1% 1/2W	306209
R213	" "	100 kΩ 5% 1/2W	301135
R214	" "	33.2 kΩ 1% 3/8W	340421
R215	" "	100 kΩ 1% 3/8W	326501
R216	" "	47 kΩ 5% 1/2W	301127
R217	" "	100 kΩ 5% 1/2W	301135
R218	" "	560 kΩ 5% 1/2W	301153
R219	" "	33 Ω 5% 1/2W	301051
R220	" "	150 kΩ 5% 1/2W	301139
R221	" "	1 kΩ 5% 1/2W	301087
R222	" "	270 Ω 5% 1/2W	301073
R223	" "	100 kΩ 5% 1/2W	301135
R224	" "	2.7 kΩ 5% 1/2W	301097
R225	" "	820 Ω 5% 1/2W	301085
R226	" "	6.2 kΩ 5% 1/2W	301106
R227	" "	3.9 kΩ 5% 1/2W	301101
R228	" "	47 kΩ 5% 1/2W	301127
R229	" "	100 kΩ 5% 1/2W	301135
R230	" "	560 kΩ 5% 1/2W	301153
R231	" "	47 Ω 5% 1/2W	301055
R232	" "	56 Ω 5% 1/2W	301157
R233	" "	1 kΩ 5% 1/2W	301087
R234	" "	"	"
R235	" "	270 Ω 5% 1/2W	301073
R236	" "	39 kΩ 5% 1/2W	301125
R237	" "	12 kΩ 5% 1/2W	301113
R238	" "	68 Ω 5% 1/2W	301059
R239	" "	270 Ω 5% 1/2W	301073
R240	" "	2.67 kΩ 1% 3/8W	340291
R241	" "	49.9Ω 1% 3/8W	340084
R242	" "	2.7 kΩ 5% 1/2W	301097
R243	" "	5.23 kΩ 1% 1/4W	325396
R244	" "	"	"
R245	" "	"	"
R246	Resistor, variable	500 Ω 10% 1/2W	311281
R247	Resistor, fixed	5.23 kΩ 1% 1/4W	325396

Reference		Description		BEC Part No.
R301	Resistor, fixed	47 kΩ 5% 1/2W		301127
R302		Not Used		
R303		Not Used		
R304	" "	10 kΩ 5% 1/2W		301111
R305		Not Used		
R306		Not Used		
R307	" "	47 kΩ 5% 1/2W		301127
R308	" "	1 MΩ 5% 1/2W		301159
R309		Not Used		
R310	" "	220 kΩ 5% 1/2W		301143
R311	" "	100 kΩ 5% 1/2W		301135
		SEMICONDUCTORS		
A101	Op. Amplifier	LM301A		535002
A201	"	"		"
CR101	Diode	L. Pwr. Silicon	1N914	530058
CR102	"	"	"	"
to				
CR110	"	"	"	"
CR111	"	1.5 A 200 V	KBP02	532013
CR112	"	L. Pwr. Silicon	1N914	530058
CR113	Diode, Zener	16 V 5% 500 nW	1N5246B	530090
CR114	" "	"	"	"
CR115	" "	"	"	"
CR116	" "	"	"	"
CR201	Diode	L. Pwr. Silicon	1N914	530058
CR202	"	"	"	"
CR203	"	"	1N5240B	530077
CR204	"	"	1N914	530058
CR205	"	"	"	"
CR206	"	"	"	"
CR207	"	"	1N5224A	530114
CR208	"	"	1N914	530058
CR209	"	"	"	"
CR210	"	"	"	"
CR301	Diode	L. Pwr. Silicon	1N914	530058
CR302		Not Used		

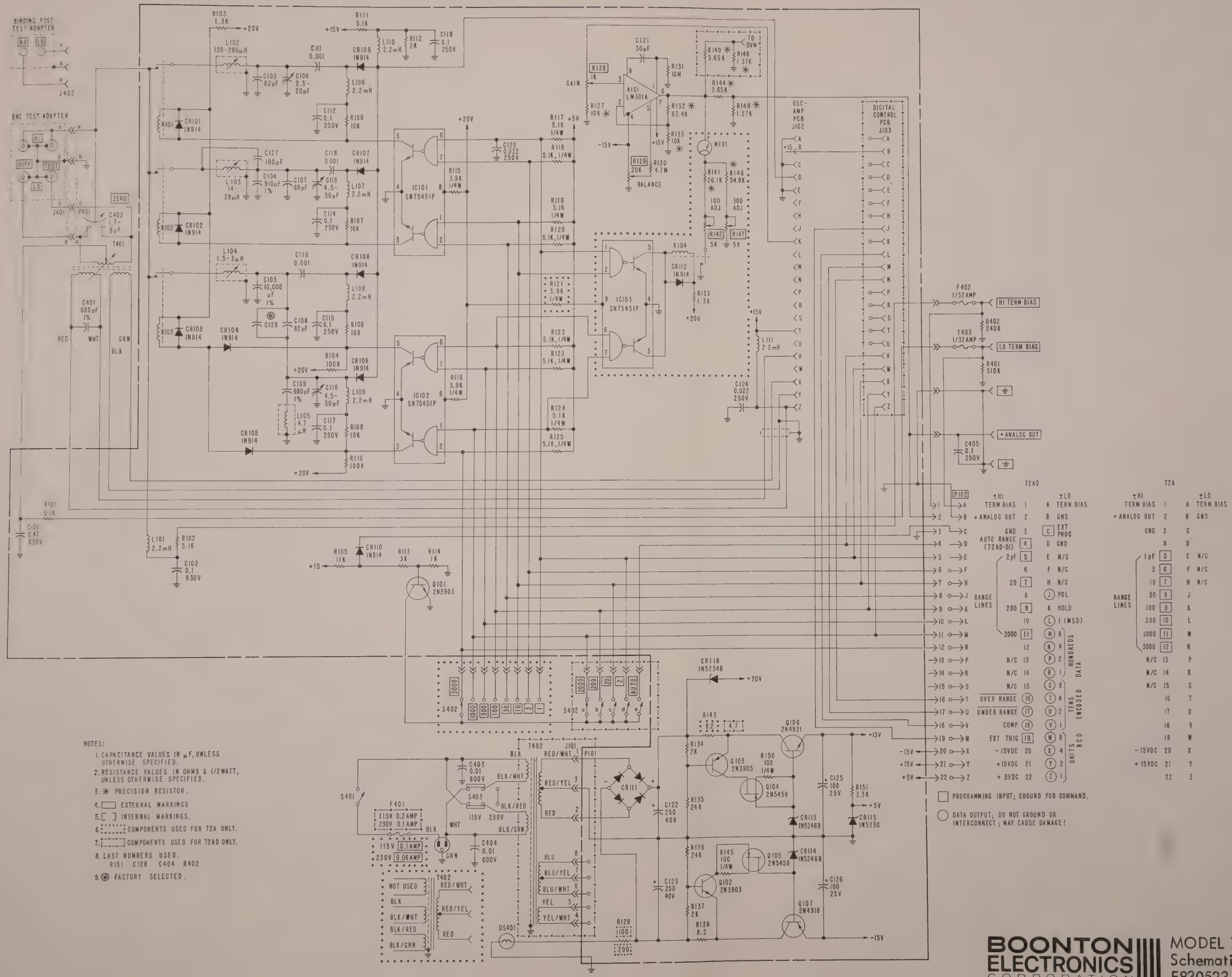
Reference		Description		BEC Part No.
CR303		Not Used		
CR304	Diode	L. Pwr. Silicon	1N914	530058
CR305 - CR308		Not Used		
CR309	Diode	L. Pwr. Silicon	1N914	530058
CR310	"	"	"	"
CR311	"	"	"	"
Q101	FET	Junction, Silicon	2N5459	528019
Q102	"	"	"	"
Q103	Transistor	PNP, Wilicon	2N3905	528025
Q104	FET	Junction, Silicon	2N5459	528019
Q105	"	"	"	"
Q106	Transistor	NPN, Silicon	2N4921	528034
Q107	"	PNP, Silicon	2N4918	528033
Q201	Transistor	Dual Gate FET	40673	528054
Q202	"	FET, Silicon	TIS58	528038
Q203	"	Junction, Silicon	2N5459	528019
Q204	"	FET, Dual Gate	40673	528054
Q205	"	"	"	"
Q206	"	NPN, Silicon	2N2219	528014
Q207	"	"	2N3903	528024
Q301		Not Used		
Q302	Transistor	NPN, Silicon	MPS6512	528059
Q303	"	"	"	"
IC101		Integrated Circuit	SN75451P	534006
IC102		"	"	"
IC103		"	"	"
IC301		Integrated Circuit	SN74L00N	534002
IC302		"	"	"
IC303		Not Used		
IC304		Integrated Circuit	SN74L00N	534002

INDUCTORS

Reference		Description	BEC Part No.
L101	Choke, RF	2.2 mH	400141
L102	Coil, RF	120 - 280 µH	400230
L103	"	14 - 28 µH	400231
L104	"	1.5 - 3 µH	400232
L105	Choke, RF	4.7 mH	400113
L106	"	2.2 mH	400141
L107 to L111	"	"	"
L201		Variable Inductor Unit	400233
L202	Choke, RF	2.2 mH	400141
L203	"	"	"
L204	"	"	"

GENERAL

F401	Fuse	0.06 A Slo Blo (230 V)	545518
F401	"	0.1 A Slo Blo (115 V)	545519
F402	"	1/32 A 250 A AGC	545525
F403	"	"	"
K101		Reed Relay	471000
K102		"	"
K103		"	"
L104		"	"
S401		Switch, On/Off	465165
S402		Switch, Rotary	466214
S403		Switch, 115/230 V	465134
T402		Transformer, Power	446052
Y201		Crystal, 1 MHz	547020
M101		Meter, Analog	554249

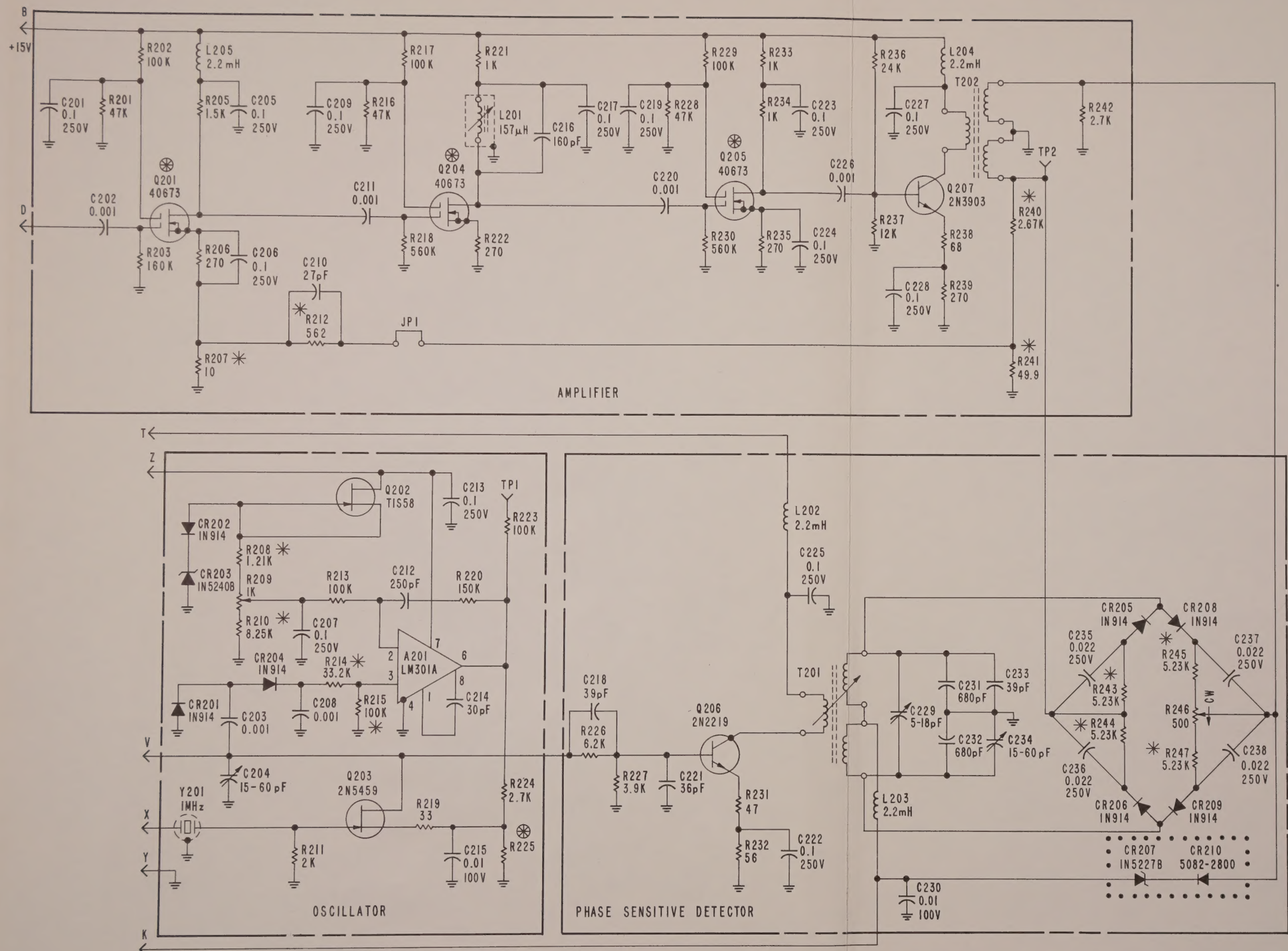


NOTES:

1. CAPACITANCE VALUES IN µF, UNLESS OTHERWISE SPECIFIED.
2. RESISTANCE VALUES IN OHMS & 1/2WATT, UNLESS OTHERWISE SPECIFIED.
3. ✳ PRECISION RESISTOR.
4. ▭ EXTERNAL MARKINGS
5. [ ] INTERNAL MARKINGS.
6. ⋯⋯ COMPONENTS USED FOR 72A ONLY.
7. ⋯[ ]⋯ COMPONENTS USED FOR 72AD ONLY.
8. LAST NUMBERS USED.
   R151 C128 C404 R402
9. ⊛ FACTORY SELECTED.

BOONTON ELECTRONICS CORPORATION

MODEL 72A/AD
Schematic, Master Board
E830523J, Sheet 1 of 2



NOTES:

1. CAPACITANCE VALUES IN µF, UNLESS OTHERWISE SPECIFIED.
2. RESISTANCE VALUES IN OHMS AND 1/2 WATT, UNLESS OTHERWISE SPECIFIED.
3. ⊛ FACTORY SELECTED VALUE.
4. ✳ PRECISION RESISTOR.
5. LAST NUMBER USED:
   R247 C238 Q207 L205
6. NUMBERS NOT USED:
   R204
7. • • • • SIGNIFIES COMPONENTS NOT USED ON 72AD-S1.

BOONTON ELECTRONICS CORPORATION

MODEL 72A, 72AD
Schematic, Osc/Amp
D830523G, Sh. 2 of 2

MP MASTER
MA24738